LA-UR -80-3161

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SUBMITTED TO: Proceedings of the Conference on Modeling of Casting and Welding Processes, August 1980, Franklin Pierce College, Runge, NH. The proceedings will be a Conference volume of the Metallurgical Society of AIME.

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COMPUTER GRAPHICS IN HEAT-TRANSFER SIMULATIONS

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Computer graphics can be very useful in the setup of heat transfer simulations and in the display of the results of such simulations. The potential use of recently available low-cost graphics devices in the setup of such simulations has not been fully exploited. Several types of graphics devices and their potential usefulness are discussed, and some configurations of graphics equipment are presented in the low-, medium-, and high-price ranges.

1. Introduction

Simulation of heat transfer during solidification has progressed over the years until now it is reported to have reached a point where its application to industrial problems can be considered. There are essentially three steps in performing such a computer simulation: the problem setup, the actual heat-transfer simulation, and the displaying of results of the simulation.

Computer graphics deals with the computer hardware and software needed to display and manipulate computer-drawn pictures. Where can computer graphics help in heat-transfer simulations? Computer graphics can make its largest contribution in the first step, problem setup. In this step, the user specifies to the computer a two- or three-dimensional heat-transfer mesh consisting of nodes, boundaries between various materials, thermal properties of various materials, etc. This mesh, being a model of a physical object, has an inherent graphical representation. Therefore it seems natural to use computer graphics input devices to specify it. However, computer graphics is not yet in general use in this step due to a lack of readily available software. This may be due, in part, to the availability only recently of inexpensive graphics devices, and in part to the different style of software design needed for interactive applications as opposed to applications designed for batch execution. The next section of this paper will consider this problem setup in detail.

In the second step, the thermal analysis calculations, computer graphics cannot provide much help. This step is traditionally performed on large mainframe computers. There now exist several well-known computer programs for performing this step.

The third step, the display of results, can and is using computer graphics. Output in the form of charts, graphs, (some with color showing temperature variations, some with temperature contours, etc.) are in moderate use now. New, inexpensive color-display devices will surely expand this usage. Section 3 will consider this step in more detail.

In Section 4 we configure a few examples of computer graphics systems, using readily available components suitable for use in heat-transfer simulations.

2. Computer Graphics In Problem Setup

Setting up a moderately complex problem for any of the well-known heat-transfer analysis programs can be tedious and costly in terms of the time required to perform the initial setup and modify it until all errors are eliminated. Mesh generator programs have helped some in this are[a]. However, these programs still require the user to specify an inherently graphical object (a mesh) in a nongraphical way: supplying a data file of coordinates of nodes, numbering of nodes and edges for later reference, etc. It is difficult to detect errors in this textual representation of the mesh. Recently available low-cost graphics input devices of all kinds have the potential to greatly simplify the problem setup phase of computer simulations, thus eliminating one of the remaining obstacles to its more widespread use. In this section, we will consider how each of several such input devices could be used in the setup of heat transfer problems. We hope that this may help motivate the production of the required software.

Locator Devices

Locator devices are graphical input devices that are used to specify an x,y position or series of positions. The data tablet is such a device, and it is a natural device for entering the positions of mesh nodes, material boundaries, etc. A data tablet consists of a flat rectangular pad with electronic sensing devices underneath. An electronic pen or stylus is moved over the rectangular tablet area, and the sensors can detect the position of the stylus on the tablet, usually with an accuracy of about 1/10 millimeter. Software that samples this position several times per second can be used to enter freehand sketches or tracings of parts into the computer. The stylus typically contains a small switch that closes when the tip is pressed down on the tablet surface. This can be used to indicate specific positions of nodes or other objects in the mesh. Data tablets come in various sizes, from about a foot square to four or five feet on a side. Smaller sizes can be purchased for about $700, with larger sizes ranging to several thousand dollars.

Other locator devices include joysticks, thumbwheels, trackballs, and various combinations of buttons and switches that control the position of a small indicator, called a cursor, upon a display screen. The user moves the cursor to the desired position with the device and then indicates this to the computer by some action. Although these devices are relatively inexpensive, they typically cannot provide the accuracy and overall versatility of a tablet. With tablets recently available in the $700 range, I think their use will become widespread.

Pick Devices

A light pen or any of a class of devices known as "pick" devices are very useful for correcting errors or making changes in heat transfer meshes. A light pen can be used to point at an area of the display screen to indicate to the software the particular point or edge of the mesh the user wants to move or delete or modify in some way. Usually, nodes and sides of mesh areas are numbered in input data files. The numbers are used to specify nodes upon which the user wants to perform some operation. With the ability to point at various nodes, there is no longer a need for the user to be aware of their numbers. This ability of graphical input devices to specify various mesh components on a display WITHOUT NAMING THE COMPONENTS is perhaps their most useful characteristic for fixing errors and modifying meshes. For less expensive graphics systems, a data tablet or other locator device can be made to simulate a pick device by a graphics software technique known as "correlation." Similarly, a pick device can be made to simulate a locator device. Thus one device can usually be used successfully to perform both types of functions.

Textual Input Devices

A keyboard or other traditional textual input device can be used for specifying boundary conditions. However, many of these parameters, such as initial temperatures, are numeric quantities that need not be specified with great accuracy (not over three significant digits). For these parameters, various types of knobs and dials can, with an appropriate visual indicator on the display screen, be used as "valuator" devices for quickly indicating to the computer an approximate value of something. However, when a very accurate or exact value is required, a keyboard is usually used.

Software

Software controlling the graphical devices should allow the user to operate them in a natural interactive man/machine "dialogue." One useful technique is to display, along one side of the graphics display, a list or "menu" of commands that the user can select. Pointing at one of these with an input device is invariably easier and less error prone than typing commands on a keyboard.

Software commands would normally include the functions available on current mesh-generating programs, such as the ability to specify lines and curves for sides of meshes and the ability to indicate how to divide mesh segments with equal or proportional spacing. In addition, well-designed software would include commands for allowing any part of the mesh to be deleted, moved, or modified in various ways. Also, the graphics system software should provide commands for quickly defining or retrieving predefined, often-used geometric shapes from disk storage, positioning them with knobs, tablet, etc., into the correct position as part of a larger mesh geometry. This facility is quite useful after the system has been in use for a while and a library of commonly used pieces has been built up. Other such libraries could contain material properties (melting points, specific heats, and various other thermal coefficients) of commonly used materials to be called up by the user. Thus the user need only specify material types and normally need not remember and enter the various properties of the material for each and every problem using that type of material.

3. Graphics in Display of Results

Display Devices

Use of any locator device should be coupled with a CRT or some other type of display that shows the effect upon the mesh of the user's actions. Recently, several low-cost raster-scan display devices have become available that use TV technology parts and low-cost memory. These displays allow the user to selectively erase and redraw specified parts of the picture, so that he can instantly view the results of correcting errors in a mesh. This is not possible with traditional storage tube displays without erasing the entire screen and redrawing the modified image. In addition, color is available on raster-scan displays. Using color to indicate different materials in a heat-transfer mesh can be very effective. Most inexpensive color displays of this type still suffer from poor resolution, but that should improve in the near future.

When purchasing such displays, resolution and the number of simultaneous displayable colors are probably the two most important parameters. Displays using TV standards can achieve resolutions of up to 640 x 480 pixels. However, experience has shown that useful work can be done with much less resolution, namely, in the 200 x 200 range. Displays in this resolution class are quite inexpensive (a few hundred dollars to about $3,000). They will have most trouble displaying meshes with many curved boundaries, and the least trouble with meshes with mostly vertical and horizontal boundaries. For finer meshes, the graphics software should provide a "zoom" capability to allow the user to quickly zoom in on an area of interest in the mesh.

Color shading techniques are well suited for displaying variations in temperature, stress, or other scalar functions over an area of the heat mesh. For less expensive displays without color or shading capabilities, contour lines of constant temperature, pressure, etc., can be used.

Hardcopy Devices

Devices for producing hardcopy pictures, especially color hardcopy, have heretofore been rather expensive or not available. However, within the last year inexpensive ($3,000 and up) color-camera attachments have become available that will attach to most raster-scan displays and produce a Polaroid picture within a minute. For better quality hardcopy, pen plotters with multiple-color pens are now available at moderate prices ($1,100 to $4,500). These devices, however, will require several minutes to plot a moderately complex mesh, and a very long time to plot color-shaded images. They are probably most useful for producing that one last hardcopy when everything is correct, to be used for presentation of results. Ink-jet plotters allow good quality with much faster plotting speeds than pen plotters, but are considerably more expensive. Impact plotters with three-color ribbons provide moderate quality and moderate speeds (2 minutes for a moderately complex shaded plot) for prices in the $12,000 range.

4. Examples of Graphics System Configurations

Small System

A very inexpensive home computer, such as the APPLE II, Ohio Scientific, or North Star, can be the basis for a small graphics system capable of setting up and displaying results for small to moderate heat transfer problems. The limiting factor in this system will be the resolution of the display and the memory available to hold the data describing the input mesh and results. Components required are the central processor, as much memory as one can afford (usually 65,000 bytes), a color TV for display, small floppy disks, small pen plotter (such as the Houston Instrument HI-PLOT), small 12-inch data tablet (such as the Summagraphics BIT-PAD-ONE), and a small printer. These components can be obtained for about $5,500 to $6,500.

Medium System

A medium-size graphics system can be configured from a small minicomputer such as the DEC LSI-11/23; a hard disk, such as recently-announced models from Advanced Electronic Design or Data Systems Design in the 10- to 20-megabyte capacity range; an inexpensive ($2,000) system terminal like the Lear Seagler ADM-3A terminal with black and white graphics option; and the same tablet, plotter, and printer as in the small system described above. Such a system will cost approximately $18,000.

Large System

A large system might employ a vector refresh black-and-white display with three-dimensional capabilities for tackling full three-dimensional simulation models (i.e., where no symmetry can be used to reduce the dimensionality). Megatek, Vector General, and other companies make such systems that interface to minicomputers, such as a DEC PDP-11/34 or similar minicomputers. With large disks, a fast electrostatic or ink-jet printer/plotter, tablet, light pen, and joystick, such a system would be in the $60,000 to $100,000 range.

5. Summary

Several types of inexpensive graphics devices have recently become available that can be used in heat transfer problem setup and display if the proper software exists to make use of them. To be maximally effective, this software should use the graphics devices in an interactive manner, coupled with a pictorial display of the mesh that is being created or modified. Inexpensive raster-scan display devices as well as inexpensive hard-copy devices are also available. All of this equipment can now be usefully employed in the problem setup phase and the result display phase of heat transfer simulations.